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Safety and Fast Horizontal Drilling Technology in Xujiahe Formation of Western Sichuan Basin

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Abstract

Xu-2 formation in Xinchang structure of Western Sichuan Basin is a dense fractured reservoir which is buried deeply. Horizontal well drilling technology can effectively develop such gas reservoir. In this paper, first horizontal well of Xinchang Structure Xin10-1H well was taken as an example, the difficulties encountered in its safety and fast drilling were analyzed and corresponding technical measures were proposed. This summary is helpful to promote the technology of safe and fast horizontal drilling in Western Sichuan Basin.

Key words: Western Sichuan; Xu-2 formation; Ultra-deep horizontal well; Drilling technology

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INTRODUCTION

Xu-2 formation gas reservoir is one of the most potential reservoirs in Xinchang structure of Western Sichuan, which is buried deeply at about 4,600-5,200m. This reservoir is mainly tight sand, with the porosity realms of 1%-4% and permeability realms of $0.06\times10^{-3}\mu m^2$. Natural productivity of this kind of reservoir is unsatisfying, because its high and stable yield producing formation is mainly dense fracture-pore reservoirs. Available exploration & development experience and pilot test in Western Sichuan suggested horizontal drilling technology can effectively develop such gas reservoir. It can not only increase the contact area between wellbore and the reservoir, but also increase its ultimate productivity and recovery factor, further more, its maintenance capability is better than fractured vertical well. However, the hard formation and complex geological situation in Xu-2 formation result in decreased rate of penetration and likely occurred in downhole complex. In this paper, the first horizontal well in Xu-2 formation of Xinchang Structure of Xin10-1H well was taken as an example, the difficulties encountered in its horizontal drilling were analyzed and corresponding technical measures were proposed. This study provides some reference for the promoting of the safety and fast horizontal drilling technology in Western Sichuan.

1. INTRODUCTION OF XIN10-1H WELL

Xin10-1H well is the first horizontal well in Xu-2 formation of Xinchang structure, Western Sichuan Basin, with drilled depth of 5815m, vertical depth of 4928.37m, horizontal displacement of 1114.81m, KOP at 4470m, maximum inclination of 88.45°, maximum hole curvature of 31.05°/30m (at 4892.3m) and target of T_3X^2 formation. The well structure is shown in Table 1.

Table 1
Well Structure Data of Xin10-1H

Spud-in No.	Bit program		Casing program	
	Hole size (mm)	Drilled depth (m)	Outer diameter (mm)	Section (m)
1	660.4	309	508	0-306.94
2	406.4	2340	346.1/339.7	0-19.31/19.31-2338.11
3	311.15	4628	273.1/244.5	0-188.79/188.79-4626.5
4	215.9	5815	177.8/139.7	0-4294.76/4294.76-5698.93

2. DIFFICULTIES ENCOUNTERED IN SAFETY AND FAST HORIZONTAL DRILLING IN XU-2 FORMATION

Safety and fast drilling is our everlasting target in drilling progress[1], while some difficulties were unavoidably encountered because of the specific geological conditions in Xu-2 formation of Xinchang structure, Western Sichuan. Take Xin10-1H well as an example, the encountered difficulties are analyzed in particular.

2.1 Challenging Deviation Control in Vertical Section

In horizontal drilling, the quality of above vertical wellbore is of critical importance, once its inclination or displacement is over standard, more complex and difficulties would occur in deviation control of later curve section and horizontal section[2~4]. For Xin10-1H well, its KOP is at 4470m and its horizontal section is at about 4628m, the distance between them is quite short, so later curve section and horizontal section drilling would be unnecessary difficult if the inclination of the vertical section is over standard. For the formations above Xu-2 of Xinchang structure, their lithology varies much and some of them have a large formation dip and likely to induce hole deviation, so some reasonable and effective measures must be taken to ensure its well bore quality.

2.2 Challenging Borehole Trace Control in Long Horizontal Section

For horizontal well, the longer it drills through the reservoir, the higher its productivity, so the horizontal section is usually designed as long as possible with any available technology[5-6]. For Xin10-1H well, its horizontal displacement is 1114.81m and horizontal section is 815m. With the increase of horizontal section, keyway and cuttings bed are likely to be formed, resulting in difficulty in tripping and sliding. For the clastic rock strata with varied lithology , this phenomenon is particularly serious and borehole trace control is harder.

2.3 Poor Drillability and Low Drilling Effectiveness

With the increase of buried depth, rock strength became harder, which means poor breaking efficiency and drillability, resulting in low drilling effectiveness. For Xu-2 formation of Xin10-1H well, it has a quartz content of 60%-90% and its rock compressive strength is rather problematic with a poor drillability of 5.5-7.5.

2.4 Challenging Mud Lubricating Property to Decrease Friction and Torque

During the progress of horizontal section drilling, the whole drilling tool usually sticks to the lower side of the wellbore, increasing the axial and radial friction. The increased friction means high resistance and high torque when tripping, which can further result in such down-hole complex as sticking[7-8]. As the key measure to lubricate the drill pipe, the lubricating property of drilling fluid must be seriously considered. If not precisely controlled, borehole is likely to collapse and further downhole complex would take place.

3. CORRESPONDING TECHNICAL MEASURES FOR SAFETY AND FAST DRILLING IN XU-2 FORMATION

According to the difficulties mentioned above, some reasonable and effective technical measures are taken in Xin10-1H well drilling progress, which can be promoted as basic technical measures for safety and fast drilling in Xu-2 formation.

3.1 Technical Measure for Deviation Control in Vertical Section of Xin10-1H Well

During the vertical drilling progress in Xu-2 formation, proper deviation controlling drilling tool assembly and reasonable construction measures must be combined to precisely control the vertical trace. For Xin10-1H well, following technical measures are taken. Tapered bottom hole assembly was applied in the first spud and timely adjusted with drilling parameters. In the second spud, drill bit and straight screw were introduced and adjusted to coordinate with tapered bottom hole assembly. In actual operation process, inclination angle is measured per 100-300m, according to the inclination situation. If it is highly deviated, enhanced reaming is applied to smooth the shoulder, or to fan the bottom with less weight on bit. Because of the proper deviation controlling drilling tool assembly and reasonable construction measures, the deviation angle of Xin10-1H well is only 1.7° at the high depth of 4470m, laying a solid foundation for latter directional drilling.

3.2 Technical Measures For Borehole Trace Control in Horizontal Section of Xin10-1H Well

3.2.1 Properly Chosen Bottom Hole Assembly

The bottom hole assembly for the third spud in build section at 4470-4628m is Φ311.15mmBIT+Φ216mm 1.5°SUB+Φ203.2mmNMDC×1+Φ203.2mmMWD＋Φ203.2mmDC×1+Φ178mmDC×3Φ127mmHWDP×30 +Φ127mmDP, the diameter of wiper block on the Φ216mm dynamical drilling tools must be no less than Φ308mm.

The bottom hole assembly for the forth spud in build section at 4628-5000m is Φ215.9mmBIT+Φ172mm1.5°S UB+Φ127mmNMDP×1+Φ178mmMWD+Φ127mmHW DP×45+Φ127mmDP, the diameter of wiper block on the Φ172mm dynamical drilling tools must be no less than Φ212mm.

The bottom hole assembly for the forth spud in horizontal section at 5000m-5815m is Φ215.9mmBIT+Φ

172mm1.25°SUB+Φ127mmNMDP×1+Φ178mmMWD +Φ127mmDP×102+Φ127mmHWDP×45 +Φ127mmDP, no wiper block is used on the Φ172mm dynamical drilling tools .

In these bottom hole assembly, dynamical drilling tools provide the main power and MWD timely measures the borehole trace, other parts coordinate with them. Practice results suggested these bottom hole assembly can properly control the borehole trace and all the progress is free of orientation adjustment.

3.2.2 Reasonably Optimized Construction Measures

Following construction measures are practiced in build section and horizontal section to ensure its borehole trace. According to the tool face orientation, WOB is properly adjusted to ensure stable bit feeding; according to down-hole condition, drilling fluid property is timely adjusted to ensure its carrying capacity and lubricating effect, so that MWD can operate normally and get borehole trace parameters timely. With the setting of reactive twist angle, WOB, pump pressure and delivery rate are all determined, inclination measuring should be enhanced to timely modify and adjust the reactive twist angle. According to the friction force and torque, the existence of cuttings bed and its condition can be decided and further measures were taken to get rid of it. Borehole trace is precisely controlled by timely monitor of well inclination and azimuth through MWD, once the inclination is abnormal or formation boundary and complex formation is encountered, site density should be tighten and effective measures should be taken to prevent highly deviation of borehole trace because of azimuth drift.

3.3 Key Technology of Optimized Bit for Safety and Fast Drilling in Xin10-1H well

In the progress of horizontal well drilling, drilling parameters and construction method should be timely adjusted according to the formation. Various parameters should be reasonably matched and such parameters as WOB, ROP, delivery rate and drilling bit should be optimized to effectively increase the rate of penetration. In Xin10-1H well, such measures as bit optimization, drilling recommendation optimization and alternative use of roller bit and PDC bit were practiced.

PK6361MC bit designed by Drilling Technology Research Institute, Shengli Petroleum Administration performs well in the second spud in Xin10-1H well with the average rate of penetration of 6.48m/h. This bit is of high stability with 6 blades, which is helpful for the prevention of highly deviation. In Xu-jiahe group, because of the existence of sand cross-stratum and its poor drillablity, bit wear phenomenon is rather grave, so the wearproof bit of HJT537GK designed by Kingdream was practiced in the third spud. In addition, two HCD505ZXPDC bit designed by Baker Hughes was introduced to drill through the gravel layer of Xu-4 formation, with respective footage of 428.13m and 567.18m, accumulated net drilling time of 365.35h and 632.05h, average ROP of about 1.17m/h and 0.9m/h. Two Baker Hughes roller bit of MX-DS55DX were also introduced at the end of the fourth spud, with respective footage of 107.84m and 102.05m, service time of 52.91h and 57.5h, average ROP of about 2.04m/h and 1.77m/h. The roller and bearing were undamaged after tripping out, setting a new record of highest ROP of single bit in Western Sichuan, Xu-2 formation.

3.4 Practiced Drilling Fluid Systems in Xin10-1H Well

Friction force and torque are rather significant in drilling the horizontal section of horizontal well, so the drilling fluid must be well qualified in suspension stability, flow properties and lubricity to ensure a smooth borehole and safety drilling. The drilling fluid system of composite metal ion polysulfonated leak proof O/W is introduced and adjusted timely in practice in the horizontal section drilling of Xin10-1H well.

3.4.1 4,628.00-5,000m Section

Prehydrated base mud was put into the recuperated composite metal ion polysulfonated drilling fluid to decrease its density, and some treating chemicals were further adopted to translate the drilling fluid to polysulfonated leak proof O/W. After proper adjustments, it was put into practice for the fourth spud and some additives and chemicals (as follows) were timely added to optimize and maintain its property.

(a) Prehydrated sulfonated additives such as RSTF, SPNH, SMP-I to maintain its property.
(b) More sulfonated additives and surfactant were added with the increase of drilling depth to improve its high temperature stability.
(c) More shale inhibiter FT-342, polyalcohol WDN-7 (with the cloud point of 90℃), borehole plugging agent FGH and FDFT-1 were added to further optimize its collapse prevention capability.
(d) Anti-sloughing agent with high solubility in acid such as LF -1, FD-2, QS-2 were periodically added to improve its plugging capability.
(e) More RH-220 and RH102 were added to maintain its lubricating property, with the biggest friction force no more than 100KN all through the deviated section. High efficiency anti-friction agent of GXJM-1 was also periodically added to prevent the casing by decreasing the friction between the drilling tools and casing.

3.4.2 5,000-5,815.00m Section

The formation encountered in this section is mainly quartz sandstone interbedded with blackshale and coalbed, such complex as borehole instability sloughing, sticking and tight pull are likely to take place, so physical method and chemical method should be combined to maintain fluid property. In practice, the density of drilling fluid should be

as low as possible for utmost protection of the reservoir, if only it can stabilize the well bore. The specific measures to optimize and maintain drilling fluid property are listed as follows:

(a) More anti-sloughing agent FT-342 and WDN-7, borehole plugging agent FGH and FDFT-1 were added to ensure borehole stability.

(b) Such additives as SMC, SMP-1, RSTF, SPNH were slowly and precisely added to control filter lose under the condition of HTHP, so that thin filter cake with high quality would formed. Besides, shearing stress of the drilling fluid was correspondingly increased and a stagnant layer was formed near the wall, and thus its erosive action was decreased.

(c) RH220 was adopted, emulsifying agent SP-80, extreme pressure lubricant RH102 and high efficiency anti-friction agent GXJM-1 were added to improve mud lubricity. In addition, such additives as FT-342 and QS-2 were added to ensure the thin filter cake with high quality. The control of solid phase was enhanced and the Kf of horizontal section should be no more than 0.1.

With above drilling fluid system and treating measures, the maximum tripping friction fore was no more than 250KN all through the horizontal section, and no pressure cast off phenomenon occurred through the 815m horizontal section drilling, ensuring a well run job.

3.5 Technical Measure for Complex Prevention and Treating in Xin10-1H Eell

Since the kill off point and horizontal section of ultra-deep horizontal well are quite deep, once complex happens it is rather troubling, so complex prevention is of critical importance. On the one hand, complex should be prevent as much as possible, on the other hand, once it happens it should be found and treated as early as possible so as to save treating time and reduce the treating difficulty.

3.5.1 Main Emergency Project

(a) Once sticking accident happens, decrease mud density and wash the wellbore with large discharge capacity to realize stuck freeing. Precisely measure the free point, exploration and casing milling can be applied if the releasing stuck agent is useless.

(b) Take "4/7" action to control wellhead whenever overflow happens. Determine the drilling fluid density according to the shut-in pressure and kill the well routinely as soon as possible. Such actions as circulation, drilling and static are forbidden.

(c) If lost circulation is serious and normal drilling can't be applied, bottom hole assembly should be simplified and pulled into the casing, and then the sealing operation carried out.

3.5.2 Main Measures for Down-Hole Complex

(a) Drilling string fracturing

Drilling string should be put out timely if it works abnormally and drilling parameters changes while ground equipment words normally, so as to avoid down-hole complex and its deterioration. The structure and material of fishing should be clarified before practicing fishing operation so as to increase its efficiency.

(b) Lost circulation and well kick

Drilling work should be stopped immediately when lost circulation and well kick happens, and effective sealing and shut-in measures should be taken timely to avoid its deterioration. Fluid level increasing in sealing operation is actually because of the high pressure gas influx rather than back production of drilling fluid, so the well must be shut in and circulation must be interrupted. If lost circulation and well kick coexist, priority should be given to sealing operation and then shut in the well. Casing pressure, standpipe pressure and flowing yield should be recorded when overflow happens, serving as reference for further killing operation.

(c) Sloughing and fall-block

Interbedded shale was encountered at the depth of 5,071-5,079m in Xin10-1H well and sloughing take place in corresponding formation. The density and shearing stress of drilling fluid was suggested to be increased before drilling into this section, to ensure drilling fluid carrying capacity and improved wellbore stability.

CONCLUSION AND SUGGESTIONS

According to the challenging of deviation control in vertical section, borehole trace control in long horizontal section, poor drillability and mud lubricating property in the horizontal drilling process in Xu-2 Formation of Xinchang structure, technical measures of safety and fast horizontal drilling was introduced, taking Xin10-1H well as an example.

(a) Make use of tapered bottom hole assembly in the first spud and introduce drill bit and straight screw into the second. In actual operation process, measure inclination angle timely and fan the bottom with less WOB to ensure the quality of deviation control.

(b) Combine dynamical drilling tools with MWD technology and take effective measures to timely adjust borehole trace according to the measured date from MWD to ensure precise control of borehole trace.

(c) Optimized roller bit and PDC bit according to the formation lithology is proven to be the key technique to increase the rate of penetration.

(d) Composite metal ion polysulfonated leak proof O/W in horizontal drilling can ensure smooth drilling operation by effectively lubricating drilling tools and reducing the friction force to be less than 250KN.

(e) Reasonable complex prevention and treating measures ensure fast drilling by reducing out-of-hole time.

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